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2175 PROGRAM: MODULAR RADAR CONCEPT (PHASE I REPORT)

A comprehensive approach to modularity to achieve a two-to-one reduction
in life-cycle costs by 1975

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JUL 22 1974

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PROBLEM

Determine the capabilities and design parameters of military and commercial radar equipments deployed by the U.S. Navy and identify specific parameters and functional design requirements for the development of modular radar systems to achieve a 2 to 1 improvement in cost effectiveness, reliability, maintainability, and logistic support.

This problem, incorporated as part of NELC's Project 2175 (2:1 improvements by 1975), was divided into seven distinct steps, or phases, as identified in table 3. This report covers Phase I, a description of the concept of modularity as applied to surface-search radar systems, as representative of all radar systems.

RESULTS

The surface-search radar transmitter and receiver groups are determined to be the most important and likely candidates for modularization efforts. In addition, standardization of duplexer, and display groups, and modulator and power supply sections is determined to be feasible and desirable. Parameters and functional design requirements are proposed for development of transmitter, receiver, duplexer, modulator, and power supply modules. It is noted that the modularity concept is also applicable to other Navy electronic systems such as communication receivers and transmitters.

RECOMMENDATIONS

Continue to develop a family of surface-search radars utilizing the common module, section, and group approach. Investigate the cost effectiveness of this approach and look at the possibility of extending the modules across other radar and electronic systems.

Specifically:

1. Develop three X-band surface-search systems:
10 kW, 50 kW, and 130 kW.
2. Develop a 130 kW C-band system.
3. Develop receiver and control circuitry having a wide range of applicability across other radar types.
4. Provide for future additions to these systems within the modular concepts for extending the performance capabilities (such as MTI).
5. Fabricate a set of modules that can be used to build up any one of the four systems. This hardware will be used to demonstrate the commonality feature.
6. Investigate display and antenna requirements, especially for small boat applications.
7. Standardize the number and amplitude of power supply voltages for modularized radar receivers and transmitters.

ADMINISTRATIVE INFORMATION

This study was performed as part of the NELC Project 2175 program under ZF 54545, Task 2, (NELC Z401220) by the Microwave Technology Division (Code 2340) under the sponsorship of the Naval Material Command. The report summarizes efforts for the period 20 September 1972 through 30 June 1973 and was approved for publication on 26 March 1974.

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INTRODUCTION

The very best in electronic equipment is never as good as desired in meeting operational requirements and maintainability, including Navy radar systems, the subject of this report. Too often a radar system is near obsolescence by the time it is operational aboard ship, and logistic costs continue to run orders of magnitude ahead of original estimates. A look at current and past acquisition practices will point out some of the inherent problems and indicate how engineering procedures and techniques, from design to acquisition and maintenance, can be radically improved.

HISTORICAL ACQUISITION APPROACH

When a radar system is judged unacceptable — does not meet current requirements, is uneconomic to maintain, has too much down time, or any other reason — new requirements and specifications are drafted and sent out for bid to competent manufacturers. The successful bidder designs a new system using circuits, devices, and techniques he believes best meet the requirements and specifications. The result is another, completely different radar system with unique operational, maintenance and training problems. If the new system is good, the transition to shipboard utilization can be fairly smooth. However, if the new system is a bad performer, the original production run may be all that is ever procured. At best, for a marginal or less than marginal system, a new contract may be awarded (probably to a different company) to improve the "bad performer," with the new contractor having to live with less than desirable design limitations.

This approach over the past many years has resulted in the Navy acquiring an inventory of about 250 different radar systems, including modifications. The quantities of each of these systems in service vary from one (Mk-12 fire-control radar) to 375 (AN/SPS-10 surface-search radar). (Reference STIC/CS-05-2-71 15 May 1972.) Most of these systems fall far short of desired performance, and at best have their own limitations.

PROBLEMS CAUSED BY PROLIFERATION

This proliferation of radar systems in the Navy inventory helped create and continues to compound an already complex Navy logistic support problem. No equipment is immune from failure, and the resultant logistic support problems of maintaining our large number of radar systems needs no detailed explanation. However, it is important to consider the fact that there is some (unknown) minimum number of systems of a particular type where support for those systems becomes impractical and economically unfeasible.

The problem becomes magnified when considering in-service systems which are marginal or unsatisfactory. If a system has a low MTBF (mean time between failure), and/or a high MTTR (mean time to repair), the Navy will probably never purchase more than the original production run — perhaps 10 to 15 systems. This low number of in-service systems militates against the establishment of fully adequate repair facilities or the adequate distribution

and availability of critical (and possibly unique) spare parts. Thus, the systems needing the most support can end up with the least.

Another critical factor, although the cause of the problem is not readily apparent, is the lower percentage of operational availability of some of the newer radar systems compared to some of the older systems. According to NAVSHIPS Tech-News of December 1972, the AN/SPS-10 and the AN/SPS-37 have higher percentages of operational availability than the newer AN/SPS-48 and the AN/SPS-52. (See table 1.)

TABLE 1. TYPICAL SHIPBOARD RELIABILITY AND MAINTENANCE COSTS.¹

Radar Equipment	Average Cost Each Repair ² (\$)	Operational Availability (% of time available)	% Parts Demands Not On Board When Needed ³
AN/SPS-10	391	93	—
AN/SPS-29	565	44	66
AN/SPS-30	1653	36	19
AN/SPS-37	142	52	51
AN/SPS-39	511	66	32
AN/SPS-40	761	46	28
AN/SPS-43	275	61	41
AN/SPS-48	1026	49	18
AN/SPS-52	973	41	50

1. Data source: NAVSHIPS TECH-NEWS, December 1972, p. 14-15.

2. Includes parts supply and labor costs

3. Reporting period 1 January - 30 June 1972

While there is a never ending desire for improved performance and maintainability of all equipment, it must be recognized that these must be achieved within the real world constraint of obtaining the maximum return on our equipment investments. We are often faced with the hard decision that another so-called improved radar system cannot be justified as cost effective.

Cost effectiveness and improved performance are not the only problems to be solved. Many ships are finding their primary power sources (ship's generators) are working at or over their design limitations. Primary power is at a premium on all but the very largest ships. In addition, the size and weight of equipment also constitute major problems aboard ship, and providing adequate radar systems aboard small ships such as river craft and SESs (surface-effect ships), becomes an almost impossible task with existing equipment.

PRESENT AND FUTURE NAVY NEEDS

The Navy needs today a series of radars that are highly reliable, flexible enough for use on a variety of platforms, easily maintained, impose a

minimum of logistic support problems, and meet current and foreseeable performance requirements achievable with today's state-of-the-art technology, all within the constraints of severe budget limitations.

It doesn't take much imagination to see that those broadly stated requirements have been brought about by the very nature of modern warfare which is changing on an almost day-to-day basis. Modern warfare analysts maintain that the next major war could last only a few weeks, or possibly only a few days. In this environment of warfare time compression, an equipment that fails and can't be immediately repaired and put back on line is less than worthless -- it can be catastrophic.

Less dramatic but no less real and important are such problems as (1) reduced manning -- which means less probability of having qualified repairmen aboard; (2) the cramped quarters of small ships such as the SES which will not allow conventional radar construction and installation; (3) the high-speed navigation needs of the SES are not compatible with the radar for DLG- or CVAN-type platforms. In line with the changing aspects of warfare, it would not be unrealistic to assume that a Navy ship of the future might have its mission so drastically changed that its existing radars could not support the new role. On this basis, it is apparent that radar systems of the immediate future should have greater flexibility in mission applications without degradation of basic operational capabilities.

The needs of the Navy for the future are twofold. First is a need to outfit new ships as they are constructed, and second there is a need to update or replace out-moded equipment. The design and development of modularized radar systems is considered the most feasible approach to fulfilling these needs. The quantities of systems needed for these two areas are an important consideration since the amount of effort to develop these systems is dependent on the size of the potential market.

According to NAVSHIPS Document 0967-006-0008 (CONF) INVENTORY OF ELECTRONICS EQUIPMENTS (ACTIVE FLEET) the number of surface-search radars presently in use and older than the AN/SPS-40 is over 800. Most of these will have to be replaced or upgraded by 1980, because they are wearing out.

New ship construction is a somewhat nebulous consideration in the current age of austerity, but even a pessimistic estimate is a minimum requirement, in surface search, of 25 to 50 radar sets per year by 1980 including small boat and SES craft.

MODULARITY, A PROPOSED SOLUTION

2175 TASK

In July of 1972 a proposal was made by the Naval Electronics Laboratory Center (NELC) to the Naval Material Command to institute a 3-year program to achieve a 2:1 improvement in cost effectiveness, reliability, maintainability, and logistics for systems such as receivers, information monitoring and control, information processing and display, and recording. Primary emphasis was to be placed on system mechanizations that marry LSI (large-scale integration) and the concept of modularity to provide these improvements.

PHILOSOPHY OF MODULAR APPROACH

Even a very cursory overview of existing radar system specifications reveals a surprising amount of similarity in operational requirements of some circuits. Such areas as the i-f amplifier, the video amplifier, power supplies, detectors, STC and ACC circuits, mixers, local oscillators, control circuits, and signal processing circuits are so similar from one radar set to another that it is obvious that a few designs could serve for nearly all the systems except for the different mechanical configurations and power supply voltages required.

The goal of the modular radar task is to design a family of radars each using the same building blocks (modules). It is obvious that no one module, say an i-f amplifier, will answer the requirements of all the Navy radars. However, it is possible that two or three similar i-f amplifier designs can fill the requirements of 75-80 percent of the Navy radar needs.

The advantage of this approach can be seen in the reduced logistics problem of supporting three amplifiers rather than hundreds. Maintenance personnel training would also be drastically reduced.

Once good standard circuits are developed, these can be specified for all new systems. This will bring in two important benefits. First, the new radar design will be using circuits of known high reliability and, second, logistics support for this new radar will already exist.

This approach will also drastically reduce the design time for new radar systems. In addition, when a technological breakthrough is achieved, which provides greater reliability, improves performance, or meets new operational requirements, the new module could be so designed that it can be retrofitted to existing modularized radar systems.

The real value of the modular approach will not be realized within the constraints of the 2175 program, which for practical purposes is limited to surface-search radar systems. The obvious extensions will be to include other functional types of radars such as air search, weapons control, weather, air traffic, height finding, etc., even conceivably across all military services. In addition, there is no good reason why an i-f amplifier in a radar could not be also used in a communications receiver or a television system. Power supply regulations are more or less the same in all electronic systems. The possible savings in original development and maintenance cost plus the increased reliability for all military electronic systems makes the future for modular concepts look extremely enticing.

It is interesting to note that the goals of the modular surface-search radar will result in modules being developed that can be directly used to meet the requirements for Marine Corps Air Traffic Control Radar, as described in Appendix A. It is anticipated that, once in production, the modularized radar system will answer many needs in a quick, efficient and economical way. The real value of this program will be in its widespread application in radar system design, development, and acquisition for full Navy use.

DEFINITIONS OF TERMS

To simplify terminology and use those definitions universally employed, the following terminology is used in this report as defined below. These definitions conform to standard Navy applications.

1. **COMPONENT:** Identifies a single electrical/electronic device that can be used individually or collectively with other devices to provide a simple function or simple functions. Examples: Resistors, Capacitors, Coils, etc.

2. **MODULE:** Identifies an assembly of electronic components designed to perform a partial function within an overall system and is so constructed as to be replaceable without requiring special tools. Modules are further classed by level:

1st **LEVEL MODULE** must meet the definition above and have the first hermetic seal between the components and the atmosphere.

2nd **LEVEL MODULE** must meet the definition and in which all components and/or 1st **LEVEL MODULES** are assembled on a single plane – does not require a 1st **LEVEL** in it – example PCB.

3rd **LEVEL MODULE** must meet the definition and may or may not have 1st and 2nd **LEVEL MODULES**, requiring three dimension.

3. **SECTION:** Identifies a module or series of modules assembled to provide or perform specific electronic functions. Examples: STC, FTC, MTI, IF, STALO, etc.

4. **GROUP:** Identifies the major elements consisting of a series of **SECTIONS** assembled to provide specific data, processing, or information which can be utilized independently or in conjunction with other groups to form a complete electronic system. Examples: Indicator Group, Antenna Group, Transmitter Group, etc.

5. **SET:** Identifies an electronic system, consisting of one or more **GROUPS** designed and assembled to perform and meet specific operational mission, functional performance requirements, or other system applications. Examples: Navigation radar set, surface search radar set, etc.

METHOD OF SHOWING FEASIBILITY

In order to accomplish the objectives of the 2175 Program, within reasonable time and cost constraints, a representative type of radar was selected. The surface-search radar was chosen because its use is widespread across all types of Navy platforms, and it is a relatively straightforward type of radar with circuits that can be used in most other types of radar systems.

The job then is to develop a family of radars that will meet the requirements for the four types of surface search radar as set forth by NAVSEC (see table 2) and accomplish this task by developing a series of modules that can be used to build up all these systems.

By the completion of the program, a group of modules will be available such that any of the four types of surface-search radars can be assembled from these modules, and will show a high degree of module interchangeability.

TABLE 2. SURFACE-SEARCH RADAR TYPE CLASSIFICATION.

- TYPE 1:** Main navigation radars for major combatant ships
(such as AN/SPS-10 and SPS-55 radar sets)
- TYPE 2:** Precision Navigation Radars in support of Type 1
(currently being filled by Raytheon Pathfinder 1500, 2502,
2840, CMC LN-66 radar sets)
- TYPE 3:** Navigation radars for major auxiliary ships.
(such as AN/SPS-53 and SPS-60 radar sets)
- TYPE 4:** Navigation radars for patrol craft and small boats
(such as Raytheon 1900, CMC LN-66 radar sets)

PLAN OF ATTACK

To accomplish these objectives the 2175 Program task was divided into seven phases (see table 3). This report covers Phase I only, to establish the basic concepts, definitions, and philosophy of modular radar.

This seven-step program will result in a study of the possible improvements, the cost advantages, and the proposed recommendations for further work as well as the hardware to show feasibility on a very practical scale. Actual systems will exist (in prototype) and complete drawings and specifications will be available. The advantages and practicality of modular radar systems will be demonstrable at the completion of this program.

TABLE 3. PHASES AND DELIVERABLES OF MODULAR RADAR TASK.

PHASE I:

Description of modular radar concept and system philosophy, including support, i.e., performance monitoring, self-test, and maintenance.

PHASE II:

Identify the specific market that is being addressed, specify the functional requirements, and illustrate the configurations which meet the market requirements. Perform a comparison between present method of equipment selection and proposed method.

PHASE III:

Specify the modular radar requirements for surface-search, navigation, collision avoidance, and Marine Corps. These requirements are to be parameters such that hardware configurations may be identified and from which common groups and sections will be identified.

PHASE IV:

Identify the generalized equipment that is to be developed to conduct the necessary tests to verify the modular radar and support concept.

PHASE V:

Fabrication of common modules based on specified parameters. Built-in test to be included.

PHASE VI:

Test functional modular groups based on specifications and identify problem areas.

TABLE 3 (Continued)

PHASE VII:

Write detail specification for prototype of entire family of modular radar.

DELIVERABLES

PHASE I: Technical Report of concept and system philosophy -- to include FY 73 progress.

PHASE II: Technical Report -- to include tradeoff comparisons. Supports options to be included.

PHASE III: Technical Report -- This technical report is to be the preliminary specifications based on modular radar requirement.

PHASE IV: Technical Report -- Identify and define equipments to meet those specifications identified in Phase III.

PHASE V and PHASE VI: Technical Report to document test procedures, results and problem areas and recommendations. Based on development functional modules.

PHASE VII: Modular radar specification (detail).

SURVEY OF EXISTING NAVY RADARS

According to STIC-CS-05-2-75, Radiation Characteristics of Electronic Equipment (U), (SECRET), there are over 250 different approved radar sets including various models and modifications in the present Navy inventory. The radar system characteristics listed in this publication were reviewed to determine if the requirements of these systems were compatible with the modularity concept. It was found that while there were no two identical systems, the differences in many areas were insignificant. Such things as pulse widths differing by a few percent would be undetectable to an operator, or a peak power output change of 10 to 20 percent would not materially affect the system performance. A 20 percent increase in transmitter power would increase the range by about 2½ percent or about an extra ½ mile on a 20-mile range. Some appreciation of the somewhat small performance variations between systems having rather large differences in equipment specification can be seen in figure 2. This chart shows the detection range for a 1.0 M² target of various surface-search radars, ranging from 10 kW to 250 kW and pulse widths from 0.05 to 1.0 µsec. (Note the tremendous difference antenna height can make although this is not a part of the original equipment specifications.) The basic specifications were close enough that standardization looked very practical.

The total cost of ownership would be a valuable thing to know. However this information is not readily available. Such things as MTTR and the average cost per repair are known, but no overall total cost has been published.

A contract has been awarded to the Autonetics Division of Rockwell International to investigate the potential cost of ownership savings that would result if the radars were built on a modular basis compared to the way the AN/SPS-55 (our newest surface-search radar) is built. The job description of this task is in Appendix B.

The possibility of commonality of functions across the various classes of radars used on one type of platform is being investigated. A contract was

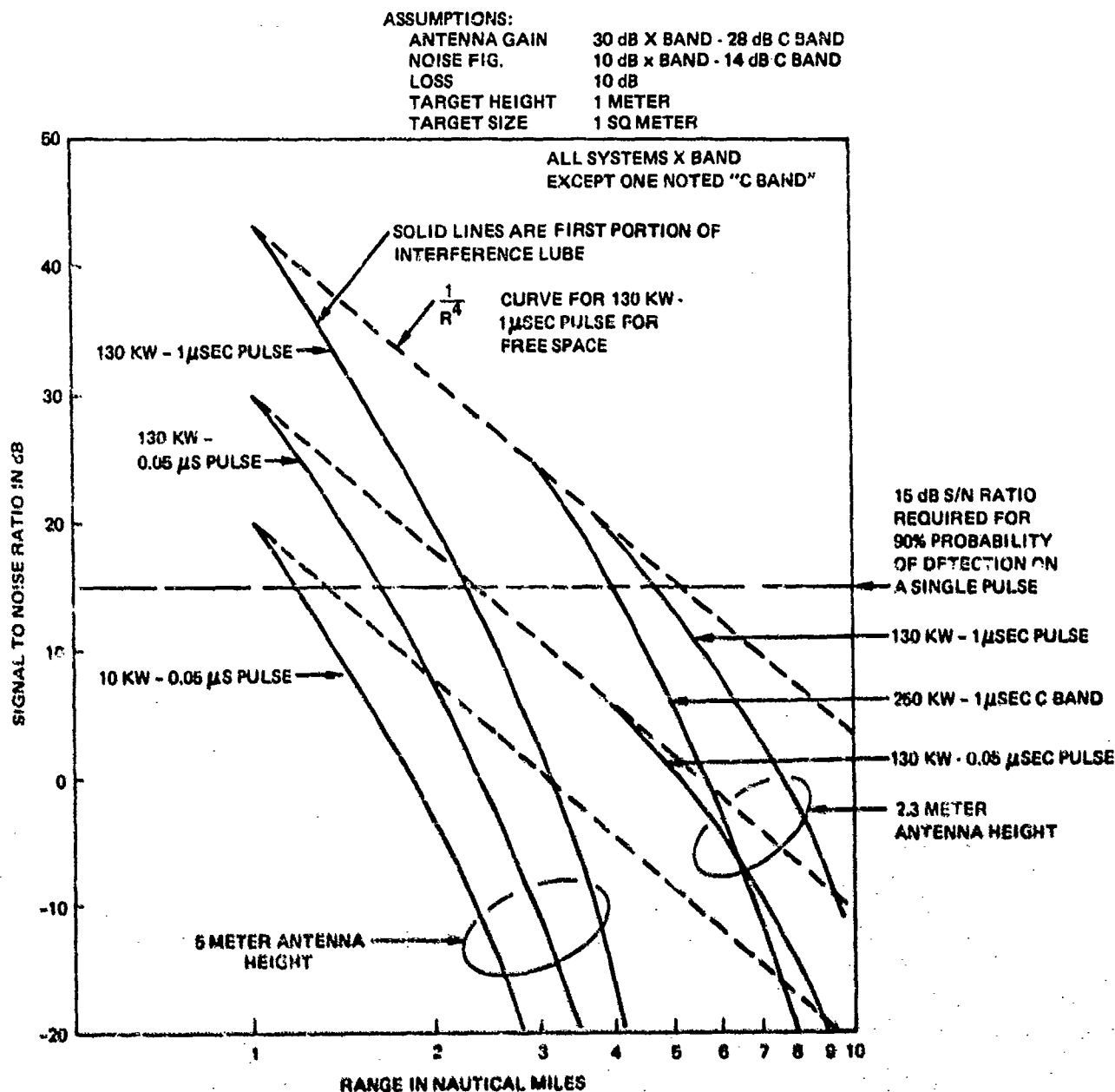


Figure 2. Performance of a variety of radars.

awarded to Westinghouse Corp. to look into the practicality of common modules across the various radars used on a DLG ship. A copy of this work agreement is in Appendix C.

It is encouraging to note that all things considered, the overall survey, the preliminary feedback on the contracts, and contacts with various technical personnel have not turned up any findings that would preclude the standardization of specifications so that common modules could be used in nearly all the Navy radars.

REQUIREMENTS FOR SURFACE-SEARCH RADAR

The operational requirements for a surface-search radar are not easily pinned down. The requirements cover a wide range of applications and any attempt to apply hardware specifications to these requirements immediately brings forth a cry from some quarter that the requirements and hardware specifications are not compatible. One of the prime objectives of the modular approach, however, is to obtain a very flexible system whose characteristics can be easily changed with the substitution of a different module or using additional modules for special functions. With this flexibility available it was decided to make the modular surface search radar family compatible with the majority of specifications of the existing radars so that those functions would be covered. This is not to say that advantage would not be taken where the new developments would allow improvements in performance.

Consistent with this basic decision we investigated the specifications of the AN/SPS-10, as it is the most populous surface-search radar, the AN/SPS-55, as it is the newest one available, the AN/SPS-60, as this one is still in the development stage and therefore represents the latest Navy requirements, and the commercial LN-66 radar as representative of the small boat type. See table 4 for a short list of general specifications for these systems.

TABLE 4. GENERAL EXISTING SPECIFICATIONS
FOR SURFACE-SEARCH RADARS.

	AN/SPS-10	AN/SPS-55	AN/SPS-60	LN 66
Freq. Band	C	X	X	X
Peak Power (KW) (Minimum)	190	130	35	10
Pulse Rate	625-650 pps	750-2250 pps	750-1500 pps	1250-2500 pps
Pulse Width	0.25-2.5 μ sec	0.12-1.0 μ sec	0.1-0.5 μ sec	0.05-0.5 μ sec
Power Tube Type	Magnetron	Magnetron	Magnetron	Magnetron
I-F Freq.	30 MHz	60 MHz	60 MHz	45 MHz
Bandwidth	1-5 MHz	1.2-10 MHz	2-12 MHz	14 MHz
Noise Figure	14 dB	10.1 dB	7 dB	11 dB
Input Power	115V 60 Hz 3 Phase	115V 60 Hz 1 Phase	115V 60 Hz 1 Phase	115V 60 Hz 1 Phase, or 12.75 Vdc

These specifications, together with the general requirements for the four types of surface-search radar as listed by NAVSEC (see table 2), have been compared with the requirements for Hydrofoil Surface-Search Radar as given in NELC TD 195 "Fleet Hydrofoil (FH) Mission Analysis and Equipment Capability Requirements for the 1980 Era" 30 June 1972 (S). The operational requirements for Marine radar as listed by the British Government in the "Marine Radar: Performance Standards, H. M. Stationary Office, 1957 and 1968 Rev." were also reviewed. A condensation of all these general requirements is given in table 5.

TABLE 5. SURFACE-SEARCH RADAR GENERAL REQUIREMENTS.

The detection range capability for the surface-search radar is, in general, to the radar horizon against small patrol craft, indigenous fishing ships, and submarine periscopes. The mast height of the craft or ship determines the actual detection ranges of the targets noted.

Requirements	Remarks
1. 160 yd thru 30 nmi	1. General requirement
2. 1 scan/sec data rate	2. Consistent with 100 knot relative speeds
3. High resolution, high clutter rejection	3. Periscope detection to horizon in high sea states
4. Provide target data to Surface-to-Surface missile	4. Redundancy for Fire Control System
5. 360° Azimuth -2° to +10° Elevation	5. General requirement
6. Continuous Automatic Target Tracking	6. 10 nmi Low-Altitude Air 20 nmi Surface targets
7. Broadband Frequency Agility	7. Reduce EM signature, reduce Target squint
8. Sector Scan capability	8. Desired
9. Antenna stabilization	9. Desirable for $\pm 15^\circ$ pitch - $\pm 45^\circ$ roll
10. Standby Mode - Electronic Emission Control capability	10. General requirements
11. Warm-up time ≤ 15 min	11. General requirement
12. High reliability	12. General requirement
13. Minimize maintenance	13. General requirement
14. Lightweight & compact	14. Less than 5000 lbs. Less than 100 cu. ft.

SPECIAL REQUIREMENTS FOR NAVIGATION

Requirements	Remarks
15. True-motion presentation	15. High speed craft requirement
16. Continuously generated PPI cursors	16. High speed craft requirement
17. Sector Scan Capability	17. High speed craft collision and debris avoidance
18. Equipment warm-up time less than 3 minutes	18. General requirement

TABLE 5. (Continued)

Requirements	Remarks
19. Very high reliability	19. MTBF more than 1000 hrs
20. Minimal maintenance	20. General requirement
21. Lightweight & compact	21. Less than 1000 lbs. Less than 100 cu. ft.
22. Interface with Computer to:	22.
A. Display simulated raw video, symbology, remote TV	A. High-speed navigation requirement
B. Perform & display closest point of approach calculations	B. (1) Range & Bearing to target (2) Course & Speed of target (3) CPA, B, and R. (4) Time to CPA (5) Audible collision — course alarm
C. Display proposed avoidance maneuver for evaluation	C. High-speed navigation requirement
D. Automatically tracks surface targets	D. 20 surface targets
E. Display intercept problem solution	E. General requirement
F. Provide information to SSM	F. Redundancy for Fire Control System

All of this has resulted in establishing a tentative set of target specifications that are being used to develop the breadboard family. These specifications are given in table 6. The peak power of the type II and IV systems was listed as 10 kW, because the prime power on small boats is very limited, and this is the power output of most existing small boat radars. This power level gives acceptable performance, and reducing the power below this value would not achieve any substantial savings in total power consumptions. The magnatron itself draws about 50 watts including the filament power. In a smaller magnatron, the efficiency is poorer, and the filament power is about the same, so that the total system power saving is very small. To reduce the transmitter power from 10 kW peak power to 1 kW, it is estimated that the overall system power would drop by less than 25 percent because the rest of the radar power needs, about 250 watts, would not change. The antenna drive alone draws about 100 watts, and is independent of the peak power. Thus a 10 kW minimum peak power seems reasonable.

The next step up in power was the Type III for which the AN/SPS-60 was specified at 35 kW peak power. As the selection of magnatrons is not too wide, we have put this requirement in a range of 35 to 50 kW. The higher powered unit for Type I use is the AN/SPS-55 at 135 kW or the AN/SPS-10 at 190-285 kW. The lower figure was chosen for our goal because the 3 dB power reduction could be easily compensated for by using a receiver with a better noise figure (the AN/SPS-10 has a 14 dB noise figure and mixers are available today off the shelf with less than 8 dB noise figures which would result in

**TABLE 6. TENTATIVE SPECIFICATIONS (PROJECT 2175)
FOR NAVSEC TYPES OF RADAR SYSTEMS.**

	Type I	Type II	Type III	Type IV
Power Tube Type	Coaxial Magnatron	Coaxial Magnatron	Coaxial Magnatron	Coaxial Magnatron
Peak Power (kW)	175 and 130	10	35	10
Freq. Band	C and X	X	X	X
Pulse Rate (PPS)	1000-2000	1000-2000	1000-2000	1000-2000
Pulse Width (μ sec)	0.050-0.500	0.050-0.500	0.050-0.500	0.050-0.500
I-f Freq. (MHz)	120	120	120	120
Bandwidth (MHz)	2-20	2-20	2-20	2-20
Noise Fig. (dB)	8	8	8	8
Input Power	115V 60 Hz 3 Phase	115V 60 Hz 3 Phase	115V 60 Hz 3 Phase	115V 60 Hz 1 Phase

receivers of about 10 dB magnitudes, corresponding to power improvement of over 2 to 1).

The pulse width of 50 msec represents about the state of the art using X-band coaxial magnatrons and will give excellent resolution for navigation purposes, and good rain clutter performance. However, at sea this narrow pulse will produce a very weak return from a small target at any appreciable distance, consequently the long pulse is also included. The 10:1 factor is about all that can be expected using typical line type modulators.

The pulse repetition rate is limited by the duty cycle requirements of the magnatron to about 2000 Hz for the longer pulse widths of 0.5 μ s. However, this is still subject to modification when the magnatrons and radar parameters are finally selected.

The 120 MHz i-f specification was chosen to allow plenty of room for wideband systems. While 60 MHz has been more traditional, this program is attempting to look far enough ahead to make provisions for improvements without the necessity of redesigning whole sections. This figure is still tentative and subject to change as the cost figures are developed.

The effect of varying the parameters of a radar system on the detection range can be seen in figure 3. It should be noted that this chart gives a relative performance compared to a hypothetical reference system and conditions. It is interesting to see the rather small difference in detection range of the LN 66 (0.05 μ sec pulse) and the AN/SPS-55 (0.1 μ sec pulse). This chart points out the rather high cost for modest improvements in performance.

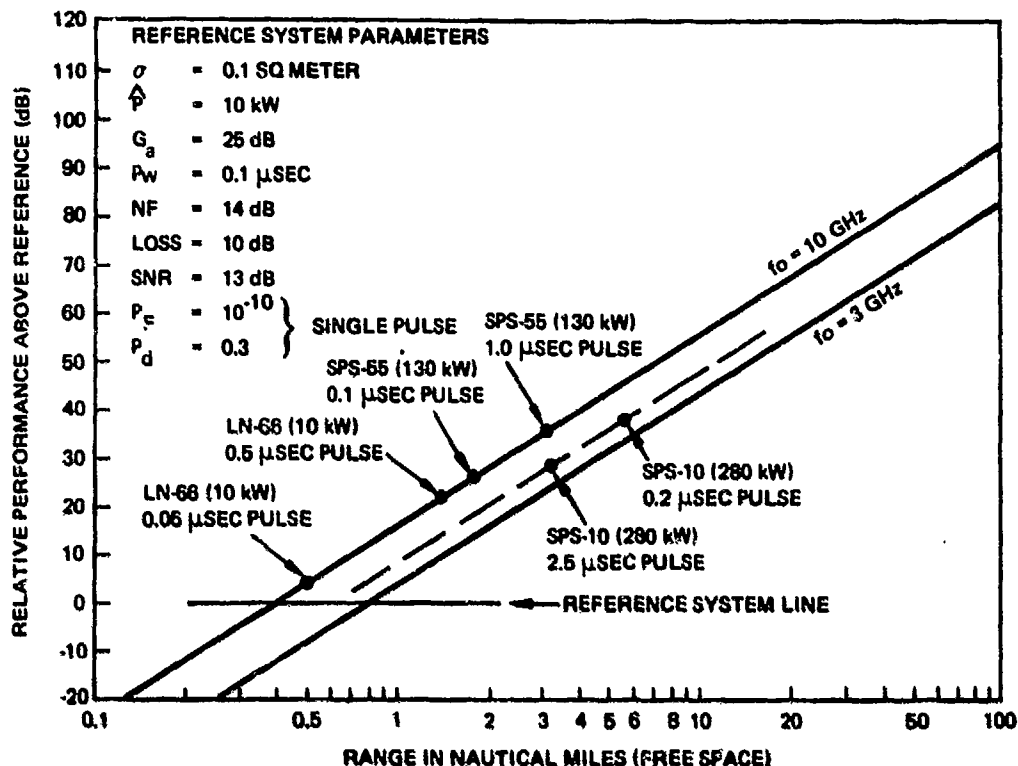


Figure 3. Radar performance comparison.

These then are the general goals for the family of modular surface search radars. It should be noted that specifics of these goals are not "cast in concrete" and can be easily modified as the program develops. They do represent a rather minimum standard from which to start.

PROJECT PROGRESS

STATE OF THE ART IN SURFACE-SEARCH RADAR CIRCUITS

The following section gives a brief resume of the present state of development for the various component parts of a surface-search radar system. In addition to current practice, interesting new developments, not quite out of the laboratory, are also mentioned. In some areas, the requirement for interchangeability is beyond the present circuit designs and some development work will be required. To simplify the discussion, it is divided into the major groups that comprise the radar set. These major groups are shown in figure 4.

TRANSMITTER

Most radar sets have been designed to perform to the limit of the state of the art at the time performance specifications were defined. As a result, each radar transmitter development has resulted in a newly developed radio frequency (rf) power tube with different high voltage and filament power supplies.

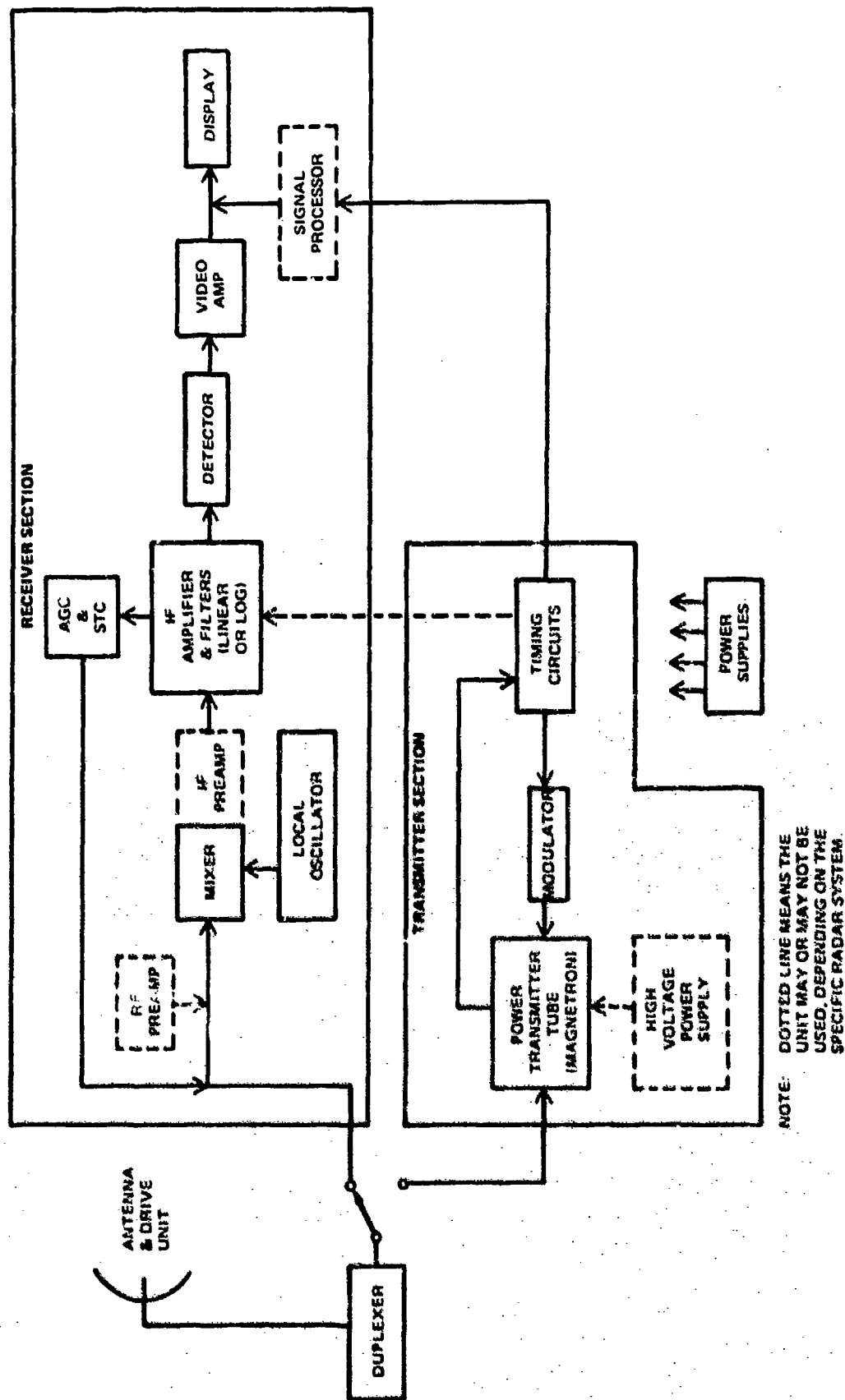


Figure 4. Major groups in a surface-search radar system.

The transmitter is the largest, heaviest, and most costly group in any radar set and it requires the most power at high voltages. It also requires the most cooling, further adding to its size, weight, and cost. Transmitter design is strongly affected by the type of rf power tube selected, as tube selection is a function of system requirements such as peak power, pulse length, bandwidth and center frequency, gain rf stability or coherency, type of processing required, etc. A block diagram of a typical radar set transmitter is shown in figure 5.

Bibliographic searches and analyses of tube characteristic data indicate that, for single ended power sources where radar equipment noise, coherency, frequency, and power requirements can be met, a coaxial magnetron type transmitter tube is preferred to an amplifier type. This is particularly true for surface-search radar where the requirements are among the least stringent. A tradeoff comparison of the various transmitter power tube types has been made and is the subject of a report to be published by code 2340 NELC. The following tube types, compared in table 7 without any priority assigned, were considered for this effort:

1. Coaxial magnetron
2. Conventional magnetron
3. Reentrant -- forward wave crossed field amplifier (CFA)
4. Non-reentrant -- forward wave CFA
5. Reentrant -- backward wave CFA
6. Non-reentrant -- backward wave CFA
7. Linear beam klystron
8. Linear beam travelling wave tube (TWT).

The importance, or weighting factor, assigned to each parameter used for evaluating these eight tube types will vary as a function of the radar set desired. For example, a small boat surface-search radar set would not require the rf stability needed for a moving target indicator (MTI) in an air-search or fire-control radar set. Consequently, the parameters and their priorities will vary for the various types of radar sets. As previously mentioned, the most numerous single type of radar set in the Navy's inventory is the surface-search type. With this type of radar, the parameters used to evaluate the eight tube types are:

1. Reliability
2. Initial cost
3. Efficiency

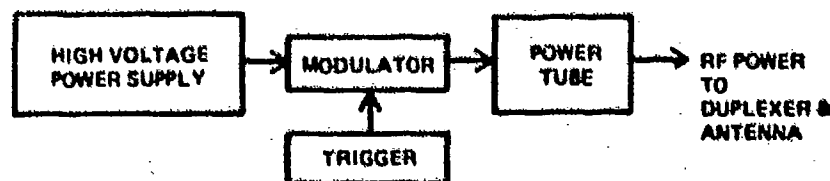


Figure 5. Transmitter block diagram.

4. Modulator and high voltage power supply complexity
5. Bandwidth
6. RF stability limitations
7. Noise and radio frequency interference (rfi) characteristics
8. Ancillary requirements
9. Size and weight considerations
10. Operating costs

A typical surface-search radar set design was selected and the 10 trade-off parameters were applied to the four basic tube types (magnetron, CFA, klystron, and TWT). To provide a fair comparison, required ancillary equipment, such as preamplifier stages, modulators, high- and low-voltage power supplies, ion pumps, electromagnetics, etc., were included with each type. For example, a CFA and a TWT driver combination with their respective power supplies and modulators was compared with a magnetron oscillator with its modulator and power supply combination to arrive at a transmitter figure of merit for a particular type of radar set. Basic characteristics of the typical surface-search radar transmitter used for comparison were:

Peak rf power -- 150 to 250 kW

Frequency -- X band

Pulse length -- 100 nanosecond and 1.0 microsecond

Duty cycle -- 0.0015

Data from more than 12 manufacturers were studied to provide the parameter tradeoffs. (Tube divisions of Varian, Raytheon, and Litton have been most helpful in supplying information on conventional and coaxial magnetrons in addition to CFAs, klystrons, and TWTs.) Table 7 indicates that the coaxial magnetron has a decided overall advantage over the CFA, klystron, and TWT where coherency, noise, and power requirements can be met. A typical tradeoff analysis between a klystron and a magnetron of essentially equal power illustrates how a 50 pound coaxial magnetron occupying 26 cubic inches can replace a klystron weighing 335 pounds (including magnet) and occupying 196 cubic inches. Appendix D lists applicable parameters.

Although figure 7 indicates the coaxial magnetron to be superior for the surface-search noncoherent radar application, its usefulness is by no means limited to this specific type of radar. Many air traffic control radars obtain a moderate MTI capability (25 dB subclutter visibility) with the conventional (noncoaxial) type magnetron using coherent on-receive only processing.

Better techniques are being developed for coherent on-receive-only processing employing phase shifting elements (either analog or digital) to shift the phase of a signal derived from a stable source. This method is superior to the technique of impulsing a local oscillator to change its phase as is employed in present coherent-on-receive-only techniques. With proper design, subclutter visibility should not be limited by the coherent-on-receive-only processing now existing in present radars. The use of these techniques with coaxial magnetrons instead of the conventional type will further improve the subclutter visibility. Coaxial S-band magnetrons could provide better than 15 dB improvement in cancellation ratio over conventional magnetrons in the air traffic control application according to analysis by Varian. However, because of other limitations, such as scan modulation and processing problems, this does not mean a full 15-dB improvement in subclutter visibility.

TABLE 7. SUMMARY OF POWER TUBE COMPARISONS

Characteristic	Klystron	Travelling Wave	Crossed Field	Magnetron	
				Conventional	Coaxial
Reliability	Very High	Moderate to Low	Moderate to High	Low	High
Cost - Tube Only	Medium	High	Medium to Low	Very Low	Low
Cost - Tube (plus preamplifiers, drivers, additional stages, power supplies, and regulators)	Medium	High	(1)	Very Low	Low
Efficiency (including ancillary stages) (percentage)	20 to 30	15 to 25	(2)	35 to 55	45 to 60
Power Supply Complexity	High	High	Medium to High	Low	Low
Modulator Complexity	High	High	Low	Low	Low
Voltage Stability Requirement	High	High	Low	Medium*	Medium*
Bandwidth	Low	High	Medium	Low	Low
Radio Frequency Stability Requirements (Spectral phase modularization)	Very High	Moderate to High	Moderate to Low	Very Low	Moderate
Low Noise and Radio Frequency Interference Generation	Very Good	Very Good	Good	Poor	Good
Ancillary Requirements (Pumps, electromagnetic fields, etc.)	High	High	Moderate	Low	Low
• Low for Noncoherent use	(1) Non-reentrant - Medium Reentrant - Low	(2) Non-reentrant - 20 to 30 Reentrant - 40 to 50			

Other techniques such as injection locking and priming of magnetrons provide additional methods of obtaining coherency. Hughes Aircraft and Litton Industries have produced injection locking gains of 23 dB at X-band with 2 degrees pulse-to-pulse phase shift. Further investigation should be continued for potential MTI and doppler application and for narrow pulse ultra-high power application (priming). Appendix A illustrates a typical air traffic control radar requirement for Marine Corps use that might make use of coaxial magnetrons operating in a coherent mode.

MODULATOR

Overall characteristics of the transmitted pulse are dependent on the quality of the marriage between the power tube (magnetron) and modulator. The shape of the pulse applied to the magnetron, and the magnetron's input characteristics determine the quality of the transmitted radar pulse. In addition, transmitter reliability is also affected by the proper interfacing of these components.

The modulator applies operating voltage to the power tube for the purpose of obtaining the required burst of rf output. The modulator, which is usually triggered by the master timer, produces a pulse to fire the master oscillator power amplifier (magnetron) in the transmitter section. Pulse amplitude and length are determined by the type of master oscillator power amplifier and modulator characteristics.

Several types of modulators were studied and tradeoff parameters applied to determine the optimum type for use with the coaxial magnetron. For the surface-search radar only two pulse lengths are required from a practical standpoint. One pulse should be as short as possible for minimum clutter (possibly 50 nanoseconds at X-band) and the other about 10 to 20 times longer (approximately 1/2 to 1 microsecond) for maximum range, on small targets. Several companies were consulted to determine the state of the art in modular type modulators for coaxial magnetrons. Among these were:

Raytheon Eastern, Mass.	Tasker Industries, CA
Varian Eastern, Mass.	Cober Electronics, Conn.
Energy Systems, CA	Axel Electronics, Inc., N.Y.
ITT Gilfillan, CA	Data Design Labs, CA

Three general types of modulators are available to provide a pulse to the magnetron; the hard tube or switching, the line type, and the magnetic. A fourth type, formed from a combination of the line and the magnetic types, is called a hybrid solid state/magnetic modulator. The hard tube modulator discharges only a fraction of the stored high voltage energy per pulse while the line type discharges essentially all the stored energy per pulse.

The tradeoff parameters between these four basic modulator types have been studied in general. A more detailed analysis will be published as a separate NELC report. Since the overall system concept stresses reliability, commonality, and overall cost of ownership, the tradeoff analysis was similar to that employed for the power tube selection. The desire for commonality will require further study because of the following considerations:

- a. Rf power levels will dictate the voltage level required in the modulator.
- b. Modulators of the same power level might be used at several rf frequency bands if consistent with pulse widths, voltage rise time, and PRF (pulse repetition frequency) requirements.
- c. Component commonality between high, medium, and low power levels might be achieved by series/parallel arrangement of elements such as silicon controlled rectifiers (SCR), diodes, etc.

Table 8 gives some pertinent comparison parameters of the four types of modulators. The conclusion is that the hybrid solid state modulator is preferred to the other types for the modular radar systems.

The main advantages of a hybrid solid state magnetic modulator as compared to a hard-tube or soft-tube or all magnetic modulator are:

1. Reduced size and weight
2. Greater efficiency
3. Higher inherent reliability
4. Longer operating life and higher MTBF
5. Lower maintenance costs
6. Less stringent high-voltage supply requirements

The disadvantages of hybrid solid state magnetic modulators are:

1. Larger pulse-to-pulse jitter
2. Lower maximum PRF than hard-tube units
3. Cannot withstand as large a load impedance mismatch as hard-tube units
4. Lower output power than soft-tube units

RECEIVER

The radar receiver is a special type of superheterodyne receiver that converts weak signals received from the antenna group into a form suitable to drive the display group or other terminal device. To accomplish this function properly, consideration must be given to such factors as carrier frequency, receiver sensitivity, signal pulse length, frequency stability, output drive requirements, etc. A simple surface-search radar receiver is represented by the block diagram, figure 6.

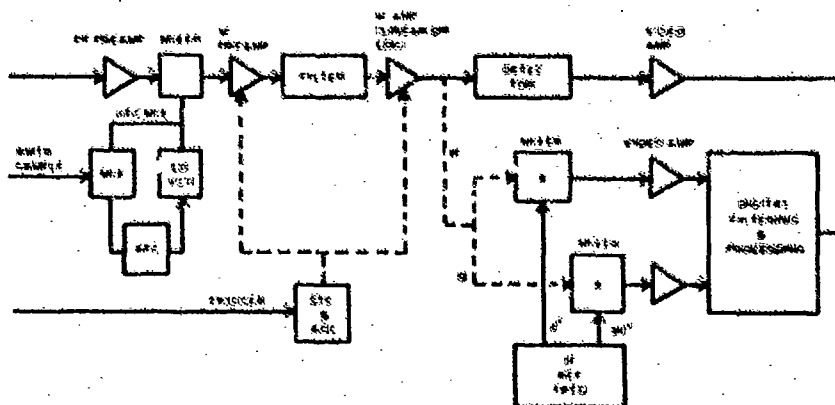


Figure 6. Receiver block diagram.

TABLE 8. MODULATOR COMPARISONS

Characteristics	Hard Tube	Line Type Soft Tube	Magnetic	Hybrid Solid State Magnetic
Efficiency (typical)	30% - 60%	40% - 65%	60% - 85%	50% - 75%
Pulse shape	Excellent* rectangular pulses. Best of group	Rise and fall time not as good as hard-tube type	Rise and fall time not as good as hard-tube type	Same as soft-tube type
Adjustable pulse width (0.5 - 5 μ sec)	Easy to achieve, can be continuously adjustable	Can provide only a few discrete widths	Multiple of prime power frequency only	Same as soft-tube type, but easier to change width
Pulse delay time	Negligible in the order of a few nsec	Not as small as hard-tube	Long delays	Relatively long 3 to 20 μ sec
Pulse time position (jitter)	Good, 1-10 nsec	Not as good as hard-tube type, 5-50 nsec	Poor	Good, 1-10 nsec
Interpulse period	May be very short, 1 μ sec or less	Relatively long, 50-100 μ sec	Long, function of power line frequency	Same as soft-tube type
Impedance matching (tube)	Wide range of mismatch permissible	Smaller mismatch: permissible +20 to \pm 30% of nominal	Same as soft-tube type	Same as soft-tube type
Power supply	Large, heavy high-voltage supply required. Typically 50% of total weight.	Supply somewhat smaller and lighter than hard-type	No high-voltage source. Uses prime unfiltered power source directly from source	No high voltage supply required. Uses power directly from source
Circuit complexity	Relatively complex	Considerably less than hard-tube type	Design critical	Between soft-tube and hard-tube type
Power output capability (peak)	Several hundred W to several MW	Tens of kW to tens of MW	Several watts to several MW	Several W to several MW
Output (watts (avg)/lb)	1 to 4	1.5 to 10	5 to 15	8 to 20

RF PREAMPLIFIER

Rf preamplifiers are not generally used at the higher frequencies (C-band and above) because the cost of such units, with sufficiently low noise figures, becomes prohibitive. Parametric amplifiers are available for use at C- and X-band frequencies but their high cost (approximately \$15,000 each) and dubious reliability rule them out except for systems that require extremely high sensitivity. Bipolar and field effect transistor (FET) amplifiers can be used with good results at lower frequencies, and the recently developed gallium arsenide FET amplifier, developing 3 to 4 dB noise figures at X-band frequencies, has shown considerable promise in laboratory circuits. Tunnel diode amplifiers have demonstrated good noise performance but their high susceptibility to burnout, low general reliability, and small dynamic range have discouraged their widespread use.

MIXER

The majority of microwave mixers use specially fabricated microwave diodes. The point contact diode had no competition for this purpose for more than 30 years until the advent of the Schottky and tunnel diodes. In all three types, resistance to burnout from spike leakage through the duplexer's receiver protection elements is about equal. The Schottky diode provides maximum pulse energy with low voltages, has a somewhat lower noise figure, and is easier to match for balanced mixer applications than the point contact diode. Consequently, at the present time, the Schottky diode is the only competitor to the point contact diode for radar receiver mixers.

Mixers are used in the configurations below and ranked by ascending cost (and approximately in performance).

Unbalanced mixer: Single diode

Balanced mixer: 1 matched diode pair

Double balanced mixer: 2 matched diode pairs

Image rejection mixer: 2 balanced mixers

Image rejection mixer: 2 double balanced mixers

Although the unbalanced mixer is the lowest in cost, its high noise figure and conversion loss are significantly greater than those of the balanced configurations. In addition, the poor input voltage standing-wave ratio (VSWR), which contributes to the high conversion loss and the amounts of local oscillator and spurious signals transmitted back toward the antenna, are further disadvantages of the unbalanced mixer.

Increases in performance, such as reduced conversion loss, lower noise levels, and fewer spurious signals, of balanced and double balanced mixers, are achieved by increases in complexity and by critical component matching, which, in turn, can result in decreased reliability. A noise figure improvement, of approximately 3 dB, is obtained with the balanced configurations over the unbalanced single-ended type because of the better noise figure of the balanced type.

The image rejection mixer is employed to reject undesired image frequencies of about 20 dB of image rejection for high quality mixers. Noise performance is slightly better for equivalent double balanced mixers. A

recently developed image rejection mixer (called image enhancement by some manufacturers), utilizing improved microwave techniques, has achieved noise figures of about 6 dB region for X-band frequencies by reconversion of the upper sideband signal to intermediate frequencies. This compares with the noise figures of 8 to 10 dB for standard image rejection and balanced mixers. The double balanced mixer appears to be the best compromise at this time.

LOCAL OSCILLATOR

The local oscillator furnishes low power to the mixer at extremely high frequency and is tunable over a wide range of frequencies. In the past, the local oscillator function was performed by either reflex klystron oscillators or klystron amplifiers driven by frequency multiplier chains. However, bipolar transistor amplifiers and oscillators, that operate below 3 gigahertz, and Gunn diode oscillators, that operate up to 50 gigahertz, are replacing the klystron oscillator even in low cost radar sets. The noise performance and simplification in the associated circuitry offsets the price differential and it is expected that by volume production of these devices their unit cost will be less than that of klystron oscillators. Development of phase-lock loop technology in conjunction with low noise oscillators has provided a large improvement in stable frequency sources for the high coherency requirements of high subclutter visibility radar sets.

INTERMEDIATE FREQUENCY PREAMPLIFIER

The intermediate frequency (i-f) preamplifier is placed physically close to, or integral with, the mixer to reduce transmission losses. The lowest loss mixer-preamplifier combination is one in which the preamplifier is designed with the mixer optimizing the match between the mixer and the i-f preamplifier for lowest noise and maximum transfer of signal. Sufficient gain should be provided to allow for losses in elements between the preamplifier and following amplifiers and to provide enough signal level that the following stages are not critical low noise stages.

The preamplifier bandwidth should be at least as wide as the widest receiver bandwidth and is determined by elements following the preamplifier. Noise figures tend to become poorer with increasing frequencies and bandwidths. Noise figures of 1.5 dB are common with i-f amplifier frequencies below 100 megahertz and rise to approximately 2 dB in the 100 to 200 megahertz region. Common i-f center frequencies are 30, 60, 120, and 160 megahertz.

LINEAR AND LOG INTERMEDIATE FREQUENCY AMPLIFIER

Bandwidth and center frequencies for log or linear i-f preamplifiers are the same. Linear i-f gain is usually greater than 60 dB and is determined by the input sensitivity of the video detector used. The video detector sensitivity can be as low as -50 dB for sensitive square-law detector diodes while higher level square law or linear detectors may have less sensitivity but higher

output. Both linear and log i-f preamplifiers are low enough in noise that, except in specialized applications, receiver bandwidths can be established by filter elements between the i-f preamplifier and amplifier.

Because of the high order of intermodulation products of log i-f amplifiers, the receiver bandwidth is determined by bandpass filtering in front of the log i-f amplifier. Two types of log i-f amplifiers are commonly employed: the successive gain-limiting stages paralleled by unity gain stages, and the successive video detection stages coupled with video delay lines. The video amplifier type is the most common and most developed even though the gain-limiting log i-f type should be the better technological approach.

The conventional log or linear i-f strip amplifier incorporates a distributed approach where each stage is designed as one part of the whole amplifier and the effect of preceding and following stages must be considered, as the tuned elements are selected to give the desired frequency characteristics. Once designed, it is not feasible to change these frequency characteristics. For use in a radar set, the design bandwidth of the i-f strip amplifier changes inversely with the transmitted pulse length. Thus, for each radar set having a different pulse length, a different i-f strip amplifier would be necessary.

To achieve a high degree of interchangeability a novel technique called the gain cell design has been developed in which the amplifier is made up of separate gain modules and lumped filter blocks, as shown in figure 7. Frequency characteristics of the overall amplifier are determined by the filter blocks while the gain is provided by the gain modules. Once laid out, frequency characteristics can be modified over a very wide range by simply replacing the filter blocks. The amplifiers have to be designed to operate over as wide a band as the various i-f requirements dictate; for instance, if it is desired to have an i-f strip amplifier with center frequencies from 30 to 160 megahertz and bandwidths up to 50 (± 25) megahertz, the gain cell must be linear (constant gain) over a bandwidth of 5 ($30 - 25$) to 185 ($160 + 25$) megahertz. In addition to this wideband characteristic, it is essential that input and output impedances be matched so that as many gain cells as necessary can be cascaded to achieve the desired overall gain.

Such gain cells are commercially available from companies such as Avantec and Optimax and have been shown to be practical in a previous NELC effort (NELC report to be published by Code 1260). The major problem experienced has been the considerable phase shift produced at high signal levels

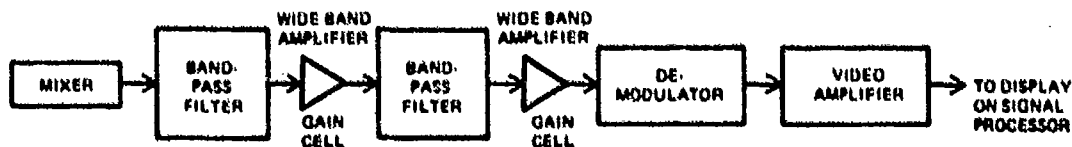


Figure 7. Block diagram of new gain cell amplifier design.

and at the higher frequencies. While this phase shift may be important for some applications, a pulse shift of only a few degrees would invalidate the operation for a MTI signal processor.

A contract was awarded to Autonetics Division of Rockwell International Corp. to investigate the possibility of limiting the phase shift. Their investigation developed a limiter that did improve phase shift performance. The findings of this effort are reported in their report, C73-610/201, "Wideband Limiter-Amplifier Phase Shift Study and Breadboard."

The final design approach is not firm at this time. More study is needed to determine the best method for the modular amplifier.

SENSITIVITY TIME CONTROL AND AUTOMATIC GAIN CONTROL CIRCUITS

Transmitted signal strength drops according to the distance travelled. Thus, a signal returned from a nearby object is much stronger than one returned from a distant object. This signal power varies approximately inversely with the fourth (and nearly the eighth power for surface target returns) of the range (or propagation time). Each amplifier has a limit, termed its dynamic range, of its ability to handle both small and large signals. Performance requirements of most radar sets necessitate handling signals over a very wide range of values.

Sensitivity time control (STC) is used to enhance the receiver's instantaneous dynamic range. This circuit automatically changes the receiver gain inversely (low gain immediately after transmitter pulse, rising with time to a higher gain proportional to the fourth power, with time).

Automatic gain control (AGC) circuitry added to the i-f strip amplifier to handle background signals, such as rain or sea clutter, provides a normalizing function so that the limited dynamic range of the amplifiers, signal processing circuits, or display systems can be effectively utilized.

The STC and the AGC circuits may each provide an input to the first stage of the i-f amplifier to change the gain. In addition, the STC usually provides an input to the duplexer section, where a variable diode attenuator may give a wider range of attenuation. These circuits are fairly straightforward, and should not present any problems in implementing in the modular format.

FILTERS

The radar receiver must select the desired echoes from various interfering signals such as other radar echoes, communication band signals, and noise. To accomplish this task, filters are used to restrict the receiver bandwidth to those frequencies emitted by the transmitter.

Filters may be of a passive network type with characteristics matched to the transmitted pulse, or they may be of an active network type, such as a digital filter, or some other sort of signal processor. All radar sets in use today use some type filter in the early amplification stages to keep down interfering signals that might otherwise saturate the amplifier and effectively block the receiver.

Filters are sometimes found in the rf section of the receiver but generally are in the i-f amplifier section where tight control over the bandwidth is easier to achieve as the bandwidth characteristics of the filters are determined by the i-f amplifier. These filters are sometimes merely passive inductive capacitance (L-C) types of tuned circuits but the inductors usually are designed for use in conjunction with the capacitance associated with the amplifying elements themselves. In this case, the filter assumes the configuration of a distributed type (rather than the lumped type described above), with its frequency characteristics developed throughout the entire amplifier.

When a single-ended or double-balanced mixer is used, an undesired image frequency may be presented to the i-f amplifier. Two approaches may be taken to eliminate or minimize this interference.

1. An image rejection mixer can be used. This results in more complexity, increased costs, and lower reliability.

2. An rf filter can be used ahead of the mixer to limit the bandwidth. This introduces some signal loss and therefore adversely affects the noise figure.

In most cases, specifications for the radar set will dictate the approach to be used. The specifications for the modulator radar have not yet been established.

DETECTOR

The detector section removes the carrier frequency and passes the modulation (the shape of the reflected transmitter pulse) to the video amplifier. At this point the signal contains frequency elements that range from direct current to approximately the reciprocal of the pulse length; i.e., about 20 megahertz for a 50-nanosecond pulse width video.

The detector circuit may take one of several different forms. For very simple receivers, where only the signal presence is desired, the detector may consist of nothing more than a diode; for more sophisticated receivers, a complex circuit may be required to keep close control of both amplitude and phase shift. Detectors generally fall into three types - simple diode, balanced, or coincidence phase. The selection of a particular type is determined by the functions to be performed by the radar set. More than one detector is being considered for our modular radar.

VIDEO AMPLIFIER

The signal amplitude from the detector may range from 0.01 to 1.0 volts and most display groups require a signal level of from 2 to 5 volts, therefore further amplification is usually necessary. This is accomplished by the video amplifier which, in addition to providing the necessary amplification, usually also provides a 50 to 75-ohm output impedance so that standard coaxial cables may be used to connect the receiver with the display group which may be located some distance away. Without this impedance matching, signals could be severely distorted.

Several commercial integrated circuit (IC) amplifiers are available that will meet most of the amplification requirements and the output buffers are of very simple design.

DUPLEXER

A means of rapidly switching the antenna from transmit to receive is essential for successful pulsed radar operation. This duplexing function has been accomplished by the TR (transmit/receiver) and the ATR (antitransmit/receiver). These are short slot hybrid devices employing a low pressure gas discharge to accomplish the switching function. The gas discharge is produced during the high powered transmit energy.

The more recent development of circulators and ferrite and diode limiters provides a more reliable means of duplexing and receiver protection. In addition, the diode limiter can be used as a voltage controlled attenuator in the receive mode to increase overall receiver dynamic range. (See figure 8.)

A gas discharge cell still must be used to provide receiver protection against excessive power caused by high VSWR (voltage standing-wave ratio) in the transmission line or antenna faults. This device (still referred to as a TR cell) fires only at a high power level that is above the power capability of the ferrite-diode limiter.

The infrequent initiation of the gas discharge plus the use of radioactive additives thereby eliminating the external high voltage DC keep alive power supply, results in a very long life device.

The failure modes or short life associated with the gas discharge mechanisms in the ATR and TR devices have been a major reliability problem in radars. Elimination or reduction of the use of the gas discharge mechanism through the use of ferrite and diode limiters will substantially increase the overall reliability of the system.

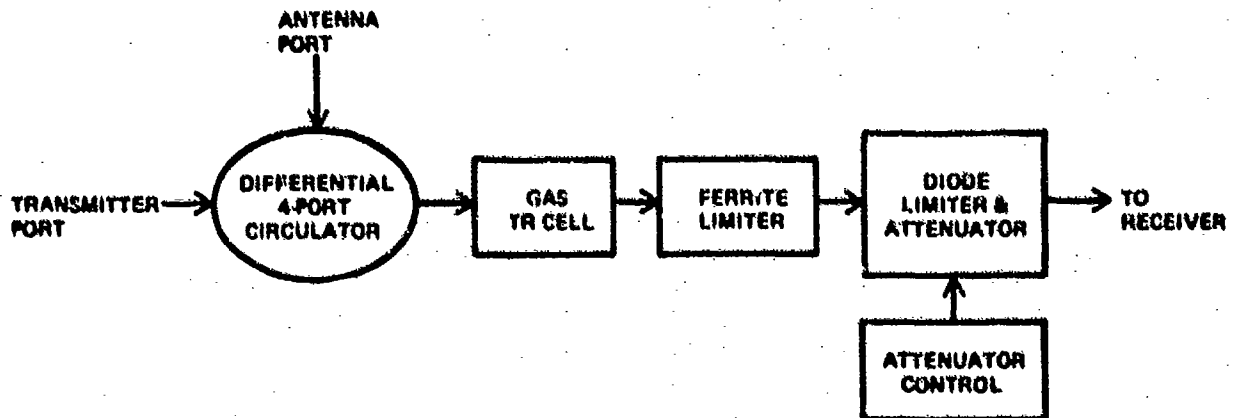


Figure 8. Duplexer block diagram.

DISPLAYS

Three standard Navy displays of primary concern for surface-search radar are employed on the AN/SPA-4A, the AN/SPA-8A, and the AN/SPA-25. Both the SPA-4 and SPA-8 are older systems that suffer from inadequate performance and reliability. The AN/SPA-25 is a relatively new solid state display that has had a history of failure caused by excessive heating. A program to modify this display has helped, and this system probably represents the best one available at this time. Even this system, however, is not suitable for the small boat where size and weight are critical.

Another problem that faces the designer of new Navy radar systems is the bandwidth limitations of existing display and video distribution systems. These systems presently are limited to about 3 to 3.5 MHz. This limitation causes the resolution of the display to be far less than that available from the rest of the radar system. Any future work should include improving the bandwidth capabilities of the display and video distribution systems.

For the Type I and II surface-search radars it is anticipated that the AN/SPA-25 display will be used. For the Type II and IV surface-search radar, a display will have to be developed. This problem will be addressed as part of this program, at least to the generation of specifications.

POWER SUPPLIES

The radar receiver and control circuits all require low voltage power sources. While some of these circuits require a well regulated voltage others operate quite satisfactorily on unregulated power. In such case, the exact voltage level used is, to a large extent, a rather arbitrary selection by the circuit designer. In the area of integrated circuits, the trend today is to use ± 12 to ± 15 volts for most linear circuits and +5 or -5 volts for digital circuits. With most solid state circuits that do not use integrated circuits, there is no recognized standard, and voltage levels typically range from 5 to 30 volts.

Voltage regulation requirements are being met very well with inexpensive integrated circuit regulators by many manufacturers. These devices are so small and economical that it is feasible to use a separate regulator on each circuit board rather than one large regulator for the entire radar set. This approach provides a higher system reliability, better performance, and shorter time to repair at costs only slightly higher than those of the single regulator approach.

Primary power to the radar set may be of several different types, depending on the platform. Small craft may have only 28 Volt direct current or 115 Volt, 60 Hertz, single phase alternating current while larger ships may have 115 Volt, 400 Hertz, single phase alternating current, 115 Volt, 60 Hertz, 3 phase alternating current, or both. A considerable reduction in power supply size and weight can be achieved with either the 60 Hertz, 3 phase, or the 400 Hertz sources. Fortunately, the larger and more powerful radar sets are used only on the larger ships. Intermediate size radar sets, however, may be used on vessels that have only a 115 Volt, 60 Hertz, single phase alternating current source and this fact must be considered during a radar set's design phase.

Provisions are being made for all possible types of primary power sources. This may result in the design of a family of modular power supplies for use on a variety of radar systems.

ANTENNAS AND PEDESTALS

The performance of a radar system is dependent on the antenna system used. The larger the antenna, for a given frequency, the higher will be its gain and the narrower its beamwidth. Thus, the largest antenna system possible should be used. However, it is obvious that a small river patrol boat can't support a 1,000-pound, 25-foot antenna and drive system.

There is a need for a family of antennas for use with the modular surface-search radar family. A large antenna is needed for most Type I applications, while for the Types II and IV installations, small 3-foot and 5-foot units are desired. The Type III system may allow an 8-foot antenna to be used. In addition, the SES type craft may require a sector scan type of antenna similar to those used on aircraft.

These problems will be investigated and specifications developed for this family of antenna systems. However, hardware will not be developed. For checkout of the modular radar concept under actual operational conditions in this program we will use existing antenna and drive systems such as those used on the AN/SPS-10, the AN/SPS-53, and the LN-66.

SUMMARY OF RESULTS

The possibility of commonality of circuits in the various Navy radars is very apparent when the specifications and operational requirements are compared. In fact the difference in performance of many radars is so small that it is undetectable as far as the visible display is concerned. An honest appraisal of the needs versus performance shows that the majority of the requirements for surface-search could be handled by two or three basic systems, and these could easily be implemented using common modules in many of the circuit areas. In addition, this family of systems can be built, on a modular basis, without requiring any extensive circuit development with the possible exception of the modulator and the duplexer. The wide ranges of power handling capability and the different frequency bands may require further development to assure maximum commonality.

CONCLUSIONS

GENERAL

With relatively few exceptions, radar equipment in use by the Navy today was designed to meet threats developed in the mid-fifties and early sixties and reflects the technology of that period. These radar sets have a short mean time between failures (MTBF) and a high time to repair (MTTR).^{*} Piecemeal equipment modifications and modernization programs have complicated the Navy's logistics problems by increasing the number of electronic line items procured, operated, and maintained. The proliferation of radar equipment has necessitated a continuing series of training and retraining programs for operating and maintenance personnel.

The desirability of having a common section for each function such as the i-f amplifier, video amplifier, power supply, detector, STC-AFC circuit, mixer, local oscillator, and output buffers is apparent even with a very cursory overview. The only reason we do not have commonality between various radar sets today is due to the way radar systems have been purchased. Each time a radar requirement has come up a set of performance specifications is written and put out for bid. After awarding the contract, the manufacturer designs his own circuit for, say, the i-f amplifier without regard to what any other system used. The result is what we have today, more than 250 radar systems with hundreds of different i-f amplifiers doing essentially the same job.

The goal of the modular radar is the design of a family of circuits that will satisfy the majority of the Navy's radar needs. This may require several versions of each basic circuit, but certainly not hundreds.

The advantages of this approach are seen in the reduced logistics problem for repair, the high degree of availability of repair parts, the reduced task of training technicians (same part used in several systems), the reduced time of system development (standard circuits can be specified), and increased reliability from using circuits known to be reliable.

A further advantage is the possibility of quickly upgrading an existing system by using state of the art technology. If the i-f amplifier is a removable module and its input and output specifications are well documented, as they would have to be for the modular radar program, it would be a simple task to unplug the old amplifiers and plug in the new improved performance unit.

Possibilities of the modular radar receivers are limited only by one's imagination. The potential saving of dollars and time, and the increased operational availability, make this approach worth implementing.

In considering those radar sets currently in use, it appears that the primary cause of problems is poor original design or antiquity. Modernization of these radar sets using the microelectronics technology available could provide a significant improvement in operational availability; however, it is a major task to update existing designs because of their mechanical construction.

^{*}Refer to "Products Generating from Fleet Reported MDCS Data for Electronic Equipment", Norfolk Division, Naval Ship Engineering Division, NAVSHIPS TECH NEWS December 1972.

Comparing the basic specifications of existing surface-search radars with the operational needs has led to the conclusion that most of these requirements can be satisfied with about three or four different designs and that within these designs a high degree of commonality can exist without requiring any serious compromise.

It appears that most surface search requirements can be met with three levels of peak power, 10 kW, 50 kW, and 130 kW at X-band, and one high power, probably 130 kW, at C-band. These figures are tentative and need to be verified. A coaxial magnetron has been selected for use in all these systems due to its long life expectancy and superior spectral performance. A hybrid solid state modulator will be used to keep the size down and for its inherent higher reliability over a thyratron type.

The receiver is an obvious candidate for modularity in radar sets (figure 6). Receivers are generally similar in all areas except in their provisions for bandwidth capability and signal processing after i-f carrier demodulation. Most elementary radar receiver modules could be assembled from off-the-shelf catalog items. This is particularly true for surface-search radar receivers with their relatively modest requirements. It appears that form factor compartmentalization and cost, rather than any inherent design problems, are the major problems in radar receiver group production. Consequently, component performance versus cost tradeoffs will be the major concerns for the design goal of a modular radar set receiver group.

Of those display groups currently in use, only the AN/SPA-25 radar display remotely approaches modern requirements. There are no adequate small Navy display groups available for use where small size and low weight are determining requirements.

A family of improved standard display groups that employ standard circuits should be developed for use with Navy radar sets.

While the antenna is an important part of the radar system, and some study work will be undertaken to determine the extent of the problem, no antennas will be built. Existing antenna systems will be used to test the prototype modular radar.

SUMMARY

A family of modular surface-search radars has been specified, based on the operational needs, existing system performance, and the state-of-the-art circuit development. This family will exhibit a large degree of commonality with all its attendant advantage without sacrificing performance. This design will alleviate or remove many of the problems facing the Navy today in regard to providing the necessary high performance without incurring prohibitive costs.

RECOMMENDATIONS

Continue to develop a family of surface-search radars utilizing the common module, section, and group approach. Investigate the cost effectiveness of this approach and look at the possibility of extending the modules across other radar and electronic systems.

Specifically:

1. Develop three X-band surface-search systems:
10 kW, 50 kW, and 130 kW.
2. Develop a 130 kW C-band system.
3. Develop receiver and control circuitry having a wide range of applicability across other radar types.
4. Provide for future additions to these systems within the modular concepts for extending the performance capabilities (such as MTI).
5. Fabricate a set of modules that can be used to build up any one of the four systems. This hardware will be used to demonstrate the commonality feature.
6. Investigate display and antenna requirements, especially for small boat applications.
7. Standardize the number and amplitude of power supply voltages for modularized radar receivers and transmitters.

APPENDIX A

U.S. MARINE CORPS AIR TRAFFIC CONTROL RADAR REQUIREMENTS

Purpose:

The purpose of this radar is to provide air control of friendly aircraft which are employed to protect Marine amphibious operations. Control of these aircraft when entering, departing, or moving within the amphibious objective area is essential.

System descriptions, capabilities, performance characteristics, and priorities are as follows:

A. System Description:

1. Weight and Size: Max weight 5000 lbs. size to fit 2½ ton truck, medium helicopters, and C-130 aircraft.
2. Interface: Shall interface with 3-D Radar Processor Group AN/TYA-18 component of Tactical Air Operations Control AN/TYQ-2 without modification. Digital azimuth data required.
3. Processing: Shall operate only in an MTI mode to provide target detection at velocities up to Mach 0.99. The MTI shall be range gated if required to resolve range ambiguities.
4. Frequency and Tuning: Frequency shall be manually tuneable from the operator's panel across the 1250-1350 MHz band.
5. Detection Probability: Shall provide a detection probability of 90 percent with no more than five false alarms per 360-degree azimuth scan with each of the following clutter/target models:
 - a. Land Clutter: Detect 1m^2 Swerling Case I target at 30 nmi with log-normal distribution and clutter. Median RCS per unit area is $-34\text{ dB (m}^2/\text{m}^2)$ with 95th percentile at -18 dB .
 - b. Rain Clutter: Detect a 1m^2 Swerling Case I immersed in 16 mm/hr rain at 80 nmi.
6. Azimuth coverage: 360°
7. Elevation coverage: $0-40^\circ$, 0-40000 feet
8. Range resolution: 0.125 nmi.
9. Azimuth resolution: 3.0 degrees
10. IFF: Integral IFF, AIMS compatibility
11. Data rate: 4-10 seconds (Variable)
12. Range: 80 nmi (see Detection Probability)
13. Remote Operation: Shall provide for remote operation up to 1000 feet from the control site or for operation with Radar Relay Set AN/TXQ-3.
14. Displays: There is no requirement for controller displays at the radar. Maintenance requires one P.P.I. and one A - scope.
15. Logistics: Components will be, to the extent possible, plug-in/quick change, modular construction, small hermetically sealed, encapsulated or potted circuit of a throw-away nature, to be replaced rather than repaired in the Marine Corps tactical environment. The use of throw-away parts shall be used whenever possible, consistent with reliability, life expectancy, and cost effectiveness.

B. Priority of Performance Characteristics:

1. Clutter performance
2. Reliability (MTBF 500 hrs)
3. Maintainability (MTTR 1 hr)
4. Size and weight

APPENDIX B

AUTONETICS WORK AGREEMENT

STATEMENT OF WORK

NAVY RADAR MODULARITY STUDY

The objective of this task is to investigate phase shift characteristics associated with wideband single stage (5 MHz to 500 MHz) i-f amplifier circuits.

Investigate an approach to control the single section amplifier output phase dynamic change to within ± 2 degrees at any frequency from 10 MHz to 150 MHz for signal levels that are 20 dB (power) above the 1 dB output compression point. This technique must also show significant phase shift improvement for frequencies between 150 MHz and 500 MHz.

The design must not seriously affect the constant impedance levels of the dynamic range capability of the unlimited amplifier.

For the purpose of this task, the performance of the OPTIMAZ AH-62 or the AVANTEK UTO-511 can be considered as the starting base line specifications.

Provide demonstratable breadboard hardware which will show results of this wideband amplifier investigation while operating as described in the second paragraph above.

Also investigate a built-in-test (BIT) design, but demonstration is not required.

Provide an informal report which documents the results of this task by 29 Jun 1973.

Period of Performance: 12 Feb 1973 -- 29 Jun 1973

Point of Contact: C. W. Erickson

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APPENDIX C

DLG RADAR FUNCTIONS STUDY

(Westinghouse)

STATEMENT OF WORK

A contract was awarded to the Westinghouse Corporation as a part of the 2175 Program for the modular radar concept. The objective of this study is to provide increases in reliability and maintainability, and decreases in personnel requirements, weight, space, power and acquisition lead time while simultaneously providing significant life cycle cost savings. These objectives are to be achieved in the radar systems with the aid of modular designs. In these designs, modules will have application in more than one radar and possibly a single module will provide the same function for more than one radar. This phase of the study will be directed toward achieving these objectives by defining new modular radar configurations that will provide target detection, tracking, and weapons delivery performance that is equal to or better than that provided by present DLG (Guided Missile Frigate) radars. The study will be performed according to the following general outline and schedule.

Define Baseline

The following is a list of the types of radars currently aboard DLG ships. It is assumed that the functions and capabilities of these equipments will be required aboard a future DLG. Therefore these radars will be used to establish a baseline for radar requirements and comparisons. The present equipments are shown parenthetically.

- a. Long Range Search Radar (SPS-40)
- b. Surface-Search Radar (SPS-10)
- c. 3D Search Radar (SPS-48)
- d. Fire Control Track Radar (SPG-53)
- e. Fire Control Track/Illuminator Radar (SPG-55)
- f. IFF/SIF Secondary Radar
- g. Point Defense Radars (SPS-62)

The study is to also include other sensors, such as TV trackers, infrared trackers and ESM passive sensors. These sensors sometimes share antenna assemblies with the radar and must have their data closely correlated with the radar data. The study is to ensure that at least the current functional interfaces are maintained.

Each radar type will be partitioned into the following functional modules, as appropriate. A listing of the requirements of each functional module for each radar type will be derived.

- a. Synchronization
- b. Frequency Generation
- c. Power Amplification
- d. Duplexing
- e. Antenna and Pedestal

- f. Antenna Servo and Stabilization
- g. Receivers
- h. Signal Processor
- i. Data Processor
- j. Display
- k. Control
- l. Bite and Maintenance Equipment

Baseline Functional Evaluation

For each current radar, each of the functional assemblies will be evaluated using data to be supplied by NELC in each of the following categories:

- a. Reliability in MTBF
 - b. Maintainability in MTTR
 - c. Annual personnel requirements
 - d. Weight in pounds
 - e. Space in cubic feet
 - f. Life-cycle cost
- } NAVSHIPS data

Define New Modular System

The radar functional requirements will be analyzed and conceptual studies performed to define an overall radar system concept, determine the number and type of radars required, and identify modular solutions that can provide:

- a. More than one application of a functional module such that one radar module can be used elsewhere on the DLG ship to provide a function to another radar.
- b. Standardization whereby sub-modules of the assembly can be applied to other functional modules on the DLG ship.
- c. Configuration of functional modules such that a single module on a DLG ship can be used by multiple radar applications.

Evaluate Common Modules

Each functional module that meets at least one of the criteria of the previous steps will be evaluated for the following:

- a. Estimated Reliability
- b. Estimated MTBF
- c. Estimated Personnel Requirements
- d. Estimated Weight
- e. Estimated Space Required
- f. Estimated Life-Cycle Cost

Performance Comparison

Comparisons will be made between the evaluation of current radar assemblies and estimated common functional modules.

Documentation:

The following documents will be delivered as a result of this study:

a. Monthly status reports will be prepared at the end of each calendar month. The first report will include no less than two full weeks of effort and the last report will be incorporated in the final report.

b. A final report will be prepared at the end of this study phase. This report will summarize the study effort and contain the analyses, comparisons, evaluations and conclusions resulting from the study. In cases agreed upon between NELC and the contractor, common module requirements will be prepared where significant radar improvements can be expected.

APPENDIX D

KLYSTRON VERSUS COAXIAL MAGNETRON COMPARISON

The system requirements are:
pulse width = 0.7 μ s, duty = 0.00077,
peak power = 800 kW to 1 mW

<u>Characteristic</u>	<u>Klystron Amplifier</u>	<u>Coaxial Magnetron</u>
Frequency Range	2.7 to 2.9 GHz	2.7 to 2.9 GHz
Output Power, Peak	1.0 mW	800 kW
Heater Voltage	6.8V	10.0V
Heater Current	30A	13A
Heater Warm-up Time	10 min.	5 min.
Electromagnet	Required	None
Electromagnet Voltage	95V	None
Electromagnet Current	25A	None
Driver Tube	Required	None
Driver Power, Peak	4W	None
Peak Voltage	64.8 kV	30
Peak Current	34A	60
Input Power	2.2 kW	1.8 kW
Weight:		
Tube (approx.)	85 lbs.	50 lbs.
Driver	Unknown	None
Magnet	250 lbs.	None
X-Ray Shielding	Required	Not Required
Cooling:		
Tube (approx.)	200 ft. ³ /min.	100 ft. ³ /min.
Driver	Unknown	None
Magnet	100 ft. ³ /min.	None
Life Warranty	5000 hours	5000 hours

Size and shape comparisons between the klystron and the coaxial magnetron indicate that at least 194 cubic inches are required for installing the klystron and electromagnet whereas only 26 cubic inches are required for installing the coaxial magnetron.

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number) When a Navy radar system is declared obsolete, a new and unique system is designed and purchased. This proliferation of inventory of different kinds of radars presents major logistics, maintenance, and training problems. This report advances the concept that there is sufficient commonality of functions in radar systems to permit the design, development, and utilization of electronic modules to meet Navy radar system needs. This approach will result in a two-to-one reduction in the full life-cycle costs of radar systems. The design engineer can select modules which meet his specific needs, repairmen can insert modules to reduce down time, and systems can be updated to meet new requirements by the replacement or addition of		

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standardized modules. The surface-search radar, the most numerous in the Navy's inventory, was selected as the basis for modularity development. The report indicates that the basic modularity concept applied to surface-search is possibly applicable to other electronic systems such as command control and communications.

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